MINERALOGY - ITS APPLICATION IN MINERAL BENEFICIATION

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Minerals are the starting units to which the art and science of Mineral Beneficiation are applied and therefore, a basic study of mineralogy is an essential pre-requisite to fully comprehend the different processes involved in mineral beneficiation. As defined by Dana[1] " A Mineral is a body produced by the processes of inorganic nature, having usually a definite chemical composition and if found under favourable conditions, a certain characteristic atomic structure which is expressed in its crystalline form and other physical properties". A study of mineralogy therefore encompasses (1) Crystallography, (2) Physical Mineralogy, (3) Chemical Mineralogy, (4) Occurrence of Minerals and (5) Descriptive Mineralogy. Optical Mineralogy, texture and liberation as well as the physical characters are important in mineral beneficiation.

An ore is a solid crude as it occurs in earths crust containing one or more valuable constituent in such amounts as to constitute a promise of possible profit in extraction, treatment and sale[2] (Taggart). The ore therefore contains useful mineral and rest which is called gangue; sometimes the valuable mineral is present in an usable form as graphite, sulphur, in others it is to be processed like most metallic minerals. In both cases the quantity of such minerals in the ore is usually low and some form of upgradation is necessary before - mineral beneficiation further processing like extraction, smelting etc. - and this activity is called mineral beneficiation.

A study of the origin and formation of mineral deposits can give the reason for the development of mineral texture, likely associations and impurities but is beyond the scope of present paper.

Briefly stated, the chief modes of mineral origin are - (i) from fusion - solidification in ignious rocks, (ii) from solution - by crystallization, (iii) from vapour deposition. Under the first category the elements present in original magma while cooling gets concentrated and form into minerals when the concentration is appropriate and in the presence of other mineralisers. Depending upon the melting point, eutectic and other considerations thus specific mineral species may form. Later structural changes may force these minerals into different shapes and emplacement bodies to form mineral deposits.

From solutions, it could be either by evaporation like rock salts, potash, or from saturated solutions like limestone, gypsum, iron ores etc. By precipitation from ground waters or magnetic nature giving rise to fissure filling or vein type or replacement type of deposits. Vapour deposition is generally associated with volcanic activities.

The mineral deposits are usually emplaced in a host body which can be either igneous, sedimentary or metamorphic rock and is composed of rock forming minerals which are mostly silicates or Alumino-silicates and quartz in igneous and metamorphic rocks. Sedimentary rocks, or metamorphosed sedimentary rocks also have similar minerals present but with different textures.

Metamorphic rocks having gone through physical and chemical changes subsequent to their formation usually show comphotexture and signs of high temperature, pressure, stress, addition or substraction of elements etc. resulting in formation of mud mineral species sometimes. The original rock from which a metamorphic rock has been derived may be either igneous or sedimentary. As these rocks became involved in movements of the earths crust, they are subjected to extreme pressures accompanied usually by high temperatures - and stress changing the minerals present to the new form stable under these conditions. Although many minerals that were constituents of the original rock may still exist in it after its metamorphism, there are certain other minerals that are characteristically developed during the process. Some of the minerals peculiar to metamorphic rocks are tremolite, wollastonite, kyanite, zoisite, staurolite, talc, paragonite, grossularite. The physical structure of the rocks also will be changed, mineral particles are broken or flattened, giving a laminated structure, recrystallised, or in very high grade of metamorphism to a granularite variety. Gneiss, Mica-schist, Quartzite, slate, Schists, Marble etc. are some metamorphic rocks.

Vein Deposits

Vein minerals are most common mode of occurrence of valuable metals such as Copper, Lead, Zinc, Gold etc. The shape and general physical character of the vein depends upon the nature of the host-rock and history of its formation. It could be broad thick veins with sharp wall to wall contact to very fine, interlacing fracture filling, and stringer type in a schistose rock. In a soluble rock like limestone, it could be irregular, bulbous, vug filling etc.

When the wall or vein is not sharply defined, there are zones of finely disseminated minerals - adjacent to the main zone-decreasing in abundance - as in replacement deposits. The mineral contents of a vein deposit depend chiefly upon the chemical composition of the waters from which its minerals have crystallised - common are Pyrite (FeS_2), Chalcopyrite ($CuFeS_2$), Galena (PbS), Sphalerite (ZnS), Chalcocite (Cu_2S), Bornite(Cu_5FeS_4), Marcasite (FeS_2), Arsenopyrite ($FeAsS$), Stibnite (Sb_2S_3), Tetrahedrite ($Cu_6Sb_2S_7$) etc. Besides many non-metallic minerals are also found in veins such as Calcite($CaCO_3$), Dolomite Ca Mg $(CO_3)_2$, Siderite $(FeCO_3)$, Barite $BaSO_4$, Fluorite CaF_2 etc.

The vein minerals may be classed from the range of temperature for this formation, as also the general association of elements like Cu-Pb-Zn veins, Gold-Quartz veins, Gold-Cu-Silver veins, Lead-Zinc veins, Cu-Fe veins. There may also be dissolution and secondary enrichments of veins.

For mineral beneficiation as well as for extraction the mineral characterisation is the first step, and is needed for selecting a suitable step for beneficiation to find causes of loss of values in tailings and middlings, impurities present, problems in extraction as also in final processing stages.

Characterisation of Minerals:

In studying the ore, characterisation of the minerals present and its inter-relationship with the gangue may be studied under the following broad headings to give an insight and guidance for processing :

1. Identification
2. Grain size
3. Texture and interlocking
4. Liberation
5. Modal analysis
6. Mineral association, alteration etc.
7. Inclusion of trace impurities

1. Identification:

Identification is the first step of mineral characterisation. Identification of the one or more valuable mineral species as also the gangue minerals present is carried out by studying the physical and chemical properties , important among them are -

A) Megascopic:

1) Colour & lustre
2) Sp.gravity
3) Hardness, streak
4) Mode of occurrence - shape, texture, cleavage, fracture
5) Taste and odour
6) Fluorescence
7) DTA-TG Analysis
8) Chemical reactions, tube test.

B) Microscopic :

1) Colour & pleochroism
2) Shape, cleavage, microtexture etc.
3) Refractive Index, Birefrenga
4) Anisotropy, internal refraction, axial angle etc.
5) Reflectivity
6) Etching and stains and contact points
7) Microhardness
8) Hot-stage microscopy

C) Micro analysis, Microprobe, XRD, TEM, SEM studies.

Identification of the mineral phases present can be only supplemented by chemical analysis - the latter cannot fulfil the former. Thus in kyanite ore for example, we are only interested in Al_2O_3 values from kyanite and need not consider non-kyanite Al_2O_3. While going by chemical analysis both alumina will report. Similarly in iron ores Fe from iron oxides is only important and not Fe contributed by iron bearing rock forming minerals.

2. Grain Size, Texture & Liberation :

After identifying the minerals present the most important step is to determine their grain size and texture. An attempt to separate them involves the need to liberate the valuable mineral from the gangue so that they form distinct identities, and may be subjected to separation depending upon difference in the properties of these species. Sometimes when more than one valuable mineral species is present it may also be apparent that the valuable minerals may be liberated from the gangue, but these are interlocked and not free to make individual concentrates meeting the smelter requirements.

After identification the most important feature in mineralogical study for beneficiation is the textural analysis and locking liberation and intergrowth pattern.

Particles of ore consist of two or more minerals are termed as locked particles and particles consist of single mineral are termed as tree or liberated particles.

Rarely any mineral deposit is found with discrete and separate mineral grains; in beach sands and placer deposits geological agents (wind,water) have produced almost perfect liberation. Since most ores are hard massive aggregates of minerals, breaking is needed to liberate them.

Liberation may take place in two ways (i) by size reduction (ii) by detachment. By size reduction the locking is restricted to a limited number of particles and thereby liberation may be increased. When the physical properties of the two minerals in a locked particle are dissimilar or bonding between them is very weak, during comminution fracture may take place preferentially along the contact boundry and thus liberation may cause by detachment.

Texture and locking type (intergrowth) analysis may be useful to know the liberation character of the mineral.

Basic intergrowth pattern of minerals may broadly be classified into the following types :

(a) Simple Intergrowth:

In this type the two mineral phases exhibit a sharp rectilinear or gently curved contact boundry. It is more common type of locking. The behaviour of such aggregates in flotation or other process may be similar, depending on the preponderence. During comminution the locked particles may become free, usually breakage is expected to take place along contact, determining factor being the size of minimum single grain for liberation.

(b) Mottled intergrowth:

A variation of simple intergrowth is the mottled or amoeba like intergrowth in which case liberation is more difficult.

(c) Graphic Intergrowth:

Graphic pattern or a regular 'eutectic', or myrmekitic intergrowth is difficult to liberate and virtually any amount of grinding will leave particles containing both phases present.

(d) Network, Boxwork or Widmanstatter type is commonly seen in Hematite-Ilmenite, Bornite or Cubanite in Chalcopyrite, in metal eutectics.

Lamellae, layered or polysynthetic types can be seen in mica, chlorite, pyrrhotite-pentlandite, clays. In all the above cases (c,d,e) separation by physical processes has severe limitations.

(e) Disseminated type contains fine droplets or blebs like emulsion, peppered and spread over of one mineral in the host mineral. It is exhibited most commonly by sulphide ores (chalcopyrite in sphalerite, pentlandite in pyrrhotite, gold, chalcopyrite in silicates).

Since disseminated minerals are only very small fraction of the total, the locked particles behave similar to the host mineral and thus account for misplaced values in many occasions, as also cause of loss in tailings. Examples are presence of copper in zinc concentrates in complex sulphide ores (Ambamata).

(f) Concentric shell, spherulitic type - In this type we find concentric layers (1-5 microns)with a core, and may be due to rhythmic precipitation, as in many iron or manganese ores as also in ocean nodules. Oolitic ores of iron also may be classed under the same group. It may be possible to separate the nodules or oolites from the host body, but it will be practically impossible to free these interlayered gangue.

(g) Shell texture - coating, mantles, corona, rimring, atoll-like appearance of one mineral over the other, or at times chemical variation between the same mineral species are exhibited at times. The other shell may or may not envelop the whole core. Examples are complex sulphides, Covellite around sphalerite, galena, pyrite, chromite with rim of lower or higher iron and serpentine. The surface layer characters will be prominant when surface phenomena is utilised, but bulk property will be that of the core. However separation in most cases of such intergrowth is difficult.

(h) Vein-type : Thin veins, stringers or sandwich-type intergrowths are very common in sulphide mineralization, carbonates, phosphates, silica and are generally occur at a subsequent placement phenomena. It is difficult to completely liberate such ores, except when thicker veins are found. At times the thick veins may separate, but stringers associated may remain in the host rock as also a thin layer over the broken surface of the host minerals and surface property of both will be alike.

In many cases the above types will be intermixed and variations occur to such an extent that a textural analysis, besides the identification is a must so as to pinpoint possible behaviour and process routes to apply. A common case is when the same mineral combination is present as simple interlocking for say 80% and rest in fine dissemination or otherwise. In such occurance, a prediction may be made for recovery of the simple interlocked portion which has become free at a coarser grind but for recovering remaining values, a finer grind will be necessary for complete liberation.

4. Modal Analysis

The minerals in ores exhibit different intergrowth with varying types of grain boundaries. In some primary ores, where the boundaries are smooth and gently curving it may be easy to liberate. But in majority of the cases where the ore exhibits replacement texture, the grain boundaries are complex and interpenetrating and hence becomes difficult to liberate the minerals. Therefore ore crushed to a certain size always contains some locked particles which may go in the tailing where the values are lost or may dilute the concentrate with other minerals.

Modal analysis exhibits the percentage of free and locked particles and such study of a feed material to the grinding circuit may be used to control grinding operation. The modal analysis of a mill feed of lead-zinc ore is given below:

Modal Analysis of a mill feed of Lead-Zinc Ore.

Mineral	Size fraction in mesh				
	-48+65	-65+100	-100+150	-150 +200	-200
	Wt(%)	Wt.(%)	Wt.(%)	Wt.(%)	Wt(%)
Free					
Galena	6.8	24.9	39.4	51.6	54.5
Sphalerite	34.2	27.8	17.8	11.9	9.4
Gangue	46.8	32.7	41.4	36.1	36.1
Locked					
Sphalerite+ gangue	6.5	2.4	0.7	0.2	-
Galena + Sphalerite	2.8	1.1	-	-	-
Galena + gangue	2.3	0.5	0.5	0.2	-
Galena + Sphalerite + gangue	0.6	0.6	0.3	-	-
	100.0	100.0	100.0	100.0	100.0

The table shows that for complete and effective liberation the material should be ground to -200 mesh. Since -100+150 mesh fraction contains minimum amount of locked particles, for all practical purposes, -100 mesh may be taken as the liberation size below which the material should be ground to get the maximum number of free particles and at the same time avoid overgrinding wherein slime losses can be avoided (e.g. kyanite, sulphides). The liberation size also helps to select the method of beneficiation, because the different methods are suitable for different size ranges, e.g., in gravity separation lumps may be separated by heavy media separation, intermediate size particles by jigging, fine size by tabling and spiral concentration similarly magnetic separation is suitable between 0.05 and 15.0 mm.

SUMMARY

ROLE OF MINERAGRAPHY IN MINERAL BENEFICIATION

LAB STUDIES
i) TEST ON MATERIALS
ii) TEST ON PROCESS
iii) TEST ON APPARATUS

* IDENTITY OF MINERALS
* TEXTURE
* RESPONSE OF MINERAL IN DIFFERENT PROCESS
* RESPONSE OF EQUIPMENTS

PROPERTIES OF MINERALS

HARDNESS

SHAPE & SIZE

CONTACT RELATION

SPECIFIC GRAVITY

MAG. PERMEABILITY

SURFACE PROPERTY

PHYSICAL ENVIRONMENT

PHYSICO-CHEM. ENVIRONMENT

TECHNIQUES USED IN MINERAGRAPHY

* MEGASCOPIC
* UV RADIATION
* MICROSCOPIC (UPTO 0.1)

ELECTRON MICROSCOPY (LESS THAN 0.1)

MICROPROBE

MEGASCOPIC

GRAVITY, COLOR, LUSTURE
STREAK, HARDNESS, CLEAVAGE,
FRACTURE

U V RADIATION : FLUOROSCENCE, PHOSPHORESCENCE

MICROSCOPIC :

- BINOCULAR - 3 DIMENSIONAL IMAGE
- USEFUL FOR DAY-TO-DAY PROCESS CONTROL
- HAND SPECIMENS
- GRIND-LIBERATION-INTERLOCKING
- INCLUSIONS, CONTAMINANTS
- OVERGRIND, DUST & SLIMES
- SEGREGATION/DISPERSION
- MAG. PROPERTY
- MICRO-CHEMICAL REACTIONS
- POLARISING MICROSCOPE

  - TRANSMITTED LIGHT

- TEXTURE, SIZE, SHAPE, INTER-LOCKING
- COLOR & PLEOCHROISM
- RI
- EXTN. ANGLE
- BIREFRINGENCE

  - REFLECTED LIGHT

- REFLECTIVITY
- INTERNAL REFLECTION
- TEXTURE INTERGROWTH
- LOCKING & LIBERATION OF OPAQUE MINERALS
- FLUOROSCENCE
- ETCH BEHAVIOUR
- EXTINCTION ANGLE
- AUTO RADIOGRAPHY
- HOT STAGE MICROSCOPY
- IMAGE ANALYSIS

ELECTRON MICROSCOPY

MINERAL IDENTIFICATION, PHASE & MICROPROBE ANALYSIS

CHARACTERIZATION OF MINERAL ASSOCIATION

- TEXTURE-BREAKAGE CHARACTER
- GRAIN SIZE-RELATIVE HARDNESS
- LIBERATION
- MODAL ANALYSIS
- ALTERATIONS, HALO
- SURFACE CONDITIONS
- INCLUSIONS
- TRACE IMPURITIES FOR SUPER-CONC.

CASE STUDIES - EXAMPLES

- BEACH SANDS
- GOLD ORES
- CALCAREOUS SAND OF DWARKA
- GRAPHITE OF PALAMAU, BHUTAN & AP
- COMPLEX SULPHIDES
- COAL - ASSAM & JHARIA MIDDLINGS
- WOLFRAMITE FROM DEGANA & BANKURA
- CHROMITE WITH SERPENTINE, QTZ & FERRUGINOUS IMP. FROM ORISSA
- Mn ORES - BHJ/BHQ & LATERITE
- BLUE DUST FOR SUPER CONCENTRATE
- MAGNETITE FOR SUPER CONCENTRATE
- Zn ORE FROM BHUTAN

TYPES OF INTERGROWTH - GENERAL

(a). 

SIMPLE INTERLOCKING
Straight OR Curved line

(b). 

MOTTLED SIMPLE

(c). 

GRAPHIC, MYRMEKITIC
= QTZ - FELDSPAR

(d). 

NETWORK, WIDMANSTATTEN
Hematite-Magnetite-Ilmenite

(e). 

LAMELLAE, POLYSYNTHETIC, INTERLAYERED
= Pentlandite, Pyrrhotite, Chl-Clay,
Graphite-Qtz.

(f). 

DISSEMINATED
= Chalcopyrite, Sphalerite, Pyrite,
Sulphides in Gangue, coal.

(g). 

CONCENTRIC, SPHURILITIC
OOLITE NODULES

(h). 

COATINGS, ENCRUSTATIONS, CORONA
= SAND - IRON OXIDE, CHROMITE

(i). 

VEIN, STRINGERS
= MOLY IN PYRITE, SILICATES, CARBONATES